The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings: Lessons from 224 Buildings

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Synopsis

Scattered case studies and anecdotal information form the "conventional wisdom" that building commissioning is highly cost-effective. Given that this belief has not been systematically or comprehensively documented, it is perhaps of no surprise that the most frequently cited barrier to widespread use of commissioning is decision-makers' lack of information pertaining to costs and associated savings.

Designed as a “meta-analysis,” this paper compiles and synthesizes published and unpublished data from real-world commissioning and retro-commissioning projects, establishing the largest available collection of standardized information on new and existing building commissioning experience in actual buildings. We analyze results from 224 buildings, representing 30.4 million square feet of commissioned space, across 21 states. We developed a detailed and uniform methodology for characterizing the results of projects and normalizing the data to maximize inter-comparisons.

For the commissioning of existing buildings, we found median energy cost savings of 15% [7% to 29% interquartile range, i.e. 25th to 75th percentiles] or $0.27/ft^2$-year, and median payback times of 0.7 years [0.2 to 1.7 years]. For new buildings, median commissioning costs were 0.6% [0.3% to 0.9%] of total construction costs or($1.00/ft^2$), yielding a median payback time of 4.8 years [1.2 to 16.6 years]. These results exclude non-energy impacts. When non-energy impacts are included cost-effectiveness increases considerably, and the net cost for new buildings is often zero or even negative. Cost-effective results occur across a range of building types, sizes and pre-commissioning energy intensities.

We find that building commissioning can play a major and strategically important role in attaining broader national energy savings goals—with a potential of $18 billion or more in savings each year. As technologies and applications change and/or become more complex in the effort to capture greater energy savings, the risk of under-performance will rise and the value of building commissioning will increase. Indeed, innovation driven by the desire for increased energy efficiency may itself inadvertently create energy waste if those systems are not designed, implemented, and operated properly.

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http://eetd.lbl.gov/emills/PUBS/Cx-Costs-Benefits.html

Introduction

Building performance problems are pervasive. Deficiencies such as design flaws, construction defects, malfunctioning equipment, and deferred maintenance have a host of ramifications, ranging from equipment failure, to compromised indoor air quality and comfort, to unnecessarily elevated energy use or under-performance of energy-efficiency strategies. Fortunately, an emerging form of quality assurance—known as building commissioning—can detect and remedy most deficiencies.

Scattered case studies and anecdotal information form the basis of the conventional wisdom among energy-management professionals that commissioning is highly cost-effective. However, given the lack of standardized information on costs and benefits of detecting and correcting deficiencies, it is perhaps of no surprise that the most frequently cited barrier to widespread use of commissioning is decision-makers' uncertainty about its cost-effectiveness.

Designed as a "meta-analysis," the major study summarized in this paper (Mills et al. 2004) compiles and synthesizes extensive published and unpublished data from buildings commissioning projects undertaken across the United States over the past two decades, establishing the largest available collection of standardized information on commissioning experience. Thorough documentation of source material, analytical approach, and detailed results can be found in the full study.

Methodology

To acquire projects for analysis, we reviewed publications from the open archival and informal literature (e.g. project reports) as well as commissioning-provider project files to identify projects that were sufficiently well documented to enable an analysis of cost-effectiveness and other factors of importance in this study. Use of the grey literature is essential for a study such as this, given that property owners who obtain commissioning services rarely fund formal publication of the process and results. Full detail on the methodology is provided in Mills et al (2004).

We developed a detailed and uniform framework for characterizing, analyzing, and synthesizing the information. The methodology expands upon the case-study protocol developed by the California Commissioning Collaborative, summarized in Friedman *et al*. (2004), placing increased emphasis on cost-benefit analysis and the characterization of deficiencies and measures. Our approach begins with defining desired metrics and indicators (Box 1), and, from these endpoints, the types of data required to enable the analysis. It is important to consider and define desirable metrics in advance of data collection efforts. We characterized and grouped buildings according to definitions used by the U.S. Department of Energy's CBECS surveys.

Documentation of project scope—steps included in the commissioning process—was collected when available (this included 69 percent of the existing buildings studied and 38 percent of the cases of new construction) (Figures 1 and 2). We identified fifteen potential steps for existing-buildings commissioning and sixteen steps for new-construction commissioning. There is no industry standard for characterizing commissioning scope.

We sought to include relevant commissioning costs born by all parties (although it may be of interest to conduct sub-analyses to evaluate the implications for different commissioning team members). Commissioning may be funded by any combination of the building owner, tenant, utility, or other third parties such as providers of research grants. Commissioning may be implemented by various parties, including but not limited to the Commissioning Agent. An important "grey area" is the cost of labor for in-house participants.

From a practical perspective, there is no one single "correct" range of commissioning costs to be included. This will depend on the audience for the analysis, e.g., a building owner may want to exclude utility rebates or financial assistance from other parties, as it is not an out-of-pocket cost, whereas a policy analyst or program evaluator would likely want to include such costs (as we have done in this study). Of primary importance is that a standard definition is used when comparing multiple projects. Using the rules laid out in Table 1, we have standardized definitions, to the extent allowed by the source data. We include costs borne by all participants, e.g. building owners, utilities, but exclude costs associated strictly with research (e.g. demonstration projects). Commissioning agent fees are often only a part of the total cost—albeit complicated to define and track—of implementing the commissioning process. (Among the projects reporting the breakdown in our sample, the median contribution of commissioning-agent fees to total commissioning costs was 67% for existing buildings and 80% for new construction.)

Two key normalizations—rarely if ever done by others--include correcting for inflation so as to meaningfully compare projects occurring across long periods of time (we used 2003 dollars), and normalizing for variations in energy prices across project (we used 2003 U.S. averages for commercial buildings). Lacking such standardization, inter-comparisons of projects are confounded in ways that can result in a loss of value for higher-level audiences such as policymakers or program evaluators. For building owners, of course, local costs and currencies are the most relevant. To illustrate the importance of these adjustments, raw (non-inflation-corrected) energy prices varied widely across our sample: electricity from $0.025 to $0.159/kWh, fuel from $2.50 to $10.22/MBTU, and hot/chilled water from $2.58 to $8.30/MBTU. Commissioning project costs from 1985 are doubled when expressed in 2003 dollars.

As commissioning is a highly variable process, it is important to develop a consistent and sufficiently specific framework for describing the problems (deficiencies) discovered through the commissioning process and the measures applied to address them. We developed the "Measures Matrix," a completed example of which is shown in Table 2. The matrix captures information on deficiencies, correlates it with the applicable building system, and characterizes these specific combinations with a unique code.

Measuring building energy use and savings is clearly central to the question of assessing cost-effectiveness. We qualified energy use and savings data by grouping it into five categories: estimated and measured, and within measured four levels of detail per the IPMVP protocols. We limited comparative pre-/post-commissioning analyses based on measured data to cases with weather-normalized data, and used all data based on engineering estimates, as weather is not a confounding factor in this case.

Irrespective of the method of determining energy savings, it should be kept in mind that a commissioning report's recommendations may be in the process of being implemented at the time energy savings data are collected. If estimates of ultimate savings are available, they should be incorporated in cost-benefit analyses. However, attention must be given to the fact that not all recommendations will necessarily have been implemented as of the time of evaluation, especially since primary documents (e.g., commissioning reports) are typically created immediately upon delivery of the recommendations. In this study, we attempted to exclude savings for measures known not to have been implemented, but otherwise included savings for measures that had not yet been implemented as of the date the project was documented.

An important caveat is that few of the primary sources quantified the benefits of all identified savings opportunities. Perhaps the largest conservatism in any cost-benefit analysis for commissioning is that energy savings are only one of many quantifiable and non-quantifiable impacts (positive or negative) (Table 3). Non-energy impacts (NEIs) include changes in maintenance costs, changes in equipment lifetime, improved productivity, reduced change orders, and improved indoor air quality. Where available, we included these impacts in our economic analysis.

Sample

Our data collection efforts yielded 224 buildings (175 projects), spanning 21 states and representing 30.4 million square feet of floor area (73 percent in existing buildings and 27 percent in new construction). These projects collectively embody $17 million ($2003) of commissioning investment. The new-construction cohort represents $1.5 billion of total construction costs.

The information represents the work of 18 known commissioning providers (Table 4). The provider is unknown (unreported in our source documents) for 16 percent of existing building project's floor area and for 62 percent of new construction project's floor area.

Among the existing buildings projects we analyzed, the most common locations were Texas and California, while for new-construction projects the most common locations were Washington, Oregon, and Montana. The median building size was 151,000 square feet for existing buildings (95,101 to 271,650 square feet inter-quartile range, i.e. 25th to 75th percentiles) and 69,500 square feet for new construction (32,268 to 151,000 square feet inter-quartile range). With the exception of the "religious worship" and "vacant" categories, our sample covered all major building types identified in the US Energy Information Administration's periodic Commercial Buildings Energy Consumption Survey. Not all data elements were available for all projects.

Findings

The top-level results are shown in Table 5. For existing buildings, we found median commissioning costs of $\$0.27/ft^2$ ($2003) [with an inter-quartile range of $0.13 to $0.45] whole-building energy savings of 15% [7% to 29%], and payback times of 0.7 years [0.2 years to 1.7 years]. For new construction, median commissioning costs were $\$1.00/ft^2$ [$\$0.49/ft^2$ to $\$1.64/ft^2$] (0.6% of total construction costs [0.3% to 0.9%]), yielding a median payback time of 4.8 years [1.2 years to 16.6 years].[1] All of these values exclude non-energy impacts, discussed in greater depth below. Extensive detail on the findings and primary sources is provided in Mills *et al* (2004). These values are based on corrections for inflation and standardized assumptions for energy prices, described in the preceding section on methodology. While, on average, these normalizations did not have a large absolute effect, adjusted values varied by up to a factor of four in individual cases. Pre-commissioning energy intensities, savings, and payback times varied among building types, as shown in Figure 3.

Our findings are conservative insofar as the scope of commissioning rarely spans all fuels and building systems in which savings may be found, not all recommendations are implemented, and significant first-cost and ongoing non-energy benefits are rarely quantified, but are important drivers for undertaking commissioning and important among the perceived benefits (Figure 4). Examples include reduced change-orders thanks to early detection of problems during design and construction, rather than after the fact, or correcting causes of premature equipment breakdown.

Where quantified, non-energy impacts in our case studies have a material positive impact on cost effectiveness. Observed non-energy benefits include reduced change-orders thanks to early detection of problems during design and construction, rather than after the fact, or correcting causes of premature equipment breakdown. We found four cases in which non-energy impacts represented a cost increase rather than savings.

For the 36 existing buildings projects providing information, information on 81 non-energy benefits was reported. Median one-time non-energy benefits were $-\$0.18/ft^2$-year for existing buildings (10 cases) and $-\$1.24/ft^2$-year for new construction (22 cases)–comparable to the entire cost of commissioning.

For 44 new-construction projects in this compilation, information on 95 non-energy benefits was reported. For this cohort, median net cost ratio declined to 0.2% of total construction costs (average value 0.0%), and 7 cases out of 22 reporting had negative net costs (Figure 5). In one case, first-cost savings achieved through commissioning resulted in a five-percent overall reduction in construction cost. Improved equipment lifetime was the most commonly reported: 19% of the cases.[2]

Deeper analysis of the results shows cost-effective outcomes for existing buildings and new construction alike, across a range of building types, sizes (Figures 6 and 7), and pre-

[1] Percentage savings are generally not available for new construction, as there is no opportunity to measure energy use in the hypothetical (not built) non-commissioned building.
[2] This is often accomplished by reductions in hunting or cycling.

commissioning energy intensities (Figure 8). The most cost-effective results—both in terms of depth of savings and payback times—occurred among energy-intensive facilities such as hospitals and laboratories. Less cost-effective results are most frequent in smaller buildings. Energy savings tend to rise with increasing comprehensiveness of commissioning (Figure 9).

The projects identify 3,500 deficiencies (11 per building, 85 projects reporting) among existing buildings and 3,305 (28 per building, 34 projects reporting) among new construction. HVAC systems present the most problems, particularly within air-distribution systems. The most common correctional measures focus on operations and control. For the subset of cases where deficiencies are paired with the measures to remedy them, information is summarized in Tables 6 and 7.

We found considerable differences between our results for existing buildings and new construction. Commissioning costs were higher in new construction, especially for larger buildings (Figure 10). In new construction commissioning, benefits are often not calculated or measured since the purpose is typically is to ensure design intent, and estimating benefits requires simulation of the building as though it had not been commissioned. This is reflected in the "bottom-line" results per unit floor area—six-fold greater energy savings and four-fold lower commissioning costs for existing buildings. It should be noted, however, that median payback times are attractive in both cases, especially when non-energy impacts are accounted for. Larger median building floor areas in our existing-buildings sample (151,000 square feet) tended to result in lower floor area-normalized costs compared to the new-construction cases (69,500 square feet). New-construction commissioning is more strongly driven by non-energy objectives such as overall building performance, thermal comfort, and indoor air quality, whereas existing-building commissioning is more strongly driven by energy savings objectives. The need for commissioning in new construction is indicated by our observation that the number of deficiencies identified in new-construction exceed that for existing buildings by a factor of three.

Conclusions

Some view commissioning as a luxury and "added" cost, yet it is only a barometer of the cost of errors promulgated by other parties previously involved in the design, construction, or operation of buildings. Commissioning agents are just the "messengers"; they are only revealing and identifying the means to address pre-existing problems.

We find that commissioning is one of the most cost-effective means of improving energy efficiency in commercial buildings. While not a panacea, it can play a major and strategically important role in achieving national energy savings goals. If the results observed across our sample are representative of the practice and potential of commissioning more broadly, significant energy savings could be achieved nationally. Specifically, if our median project performance were to be achieved over the entire commercial buildings stock (essentially an economic-potential, not adjusted for partial penetration rates) the full cost-effective potential would amount to 15-percent of the $120-billion annual energy bill for the sector (as of 2002). This translates into savings of $18 billion annually among existing commercial buildings. In practice, the fraction of the full stock ultimately reached will depend on the effectiveness of public and private efforts to build the market for this emerging service.

As noted above, our median savings numbers are certainly less than would be achieved if all buildings had been comprehensively commissioned and all recommended measures implemented. The upper-quartile existing-building commissioning savings of 29% is twice the median, which may be closer to a best-practice level of savings. Lastly, consideration of potential benefits must consider trends in the baseline. As buildings become more complex and utilize more advanced technologies, the incidence of problems and need for commissioning will only increase, hence amplifying the need for and value of commissioning.

Commissioning is underutilized in public-interest deployment programs as well as research and development activities. As technologies, controls, and their applications change and/or become more complex in an effort to capture greater energy savings, the risk of under-performance will rise and with it the value of commissioning. Indeed, innovation driven by the desire for increased energy efficiency may itself inadvertently create energy waste if those systems are not designed, implemented, and operated properly. The ultimate impact of energy efficiency research and development portfolios, as well as deployment programs, lies in no small part in the extent to which they are coupled with cost-effective quality assurance.

References

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Box 1:

Commissioning Metrics

Building Characteristics and Demographics
- Building type (using DOE/CBECS definitions), vintage, location
- Year building commissioned
- Reasons for commissioning, deficiencies identified, measures recommended

Energy utilization intensity (use or savings)
- Electricity: kWh/building-year,[3] kWh/ft^2-year
- Peak electrical power: kW/building; W/ft^2
- Fuel: MMBTU/building; kBtu/ft^2-year
- Purchased thermal energy: MMBTU/building-year; kBtu/ft^2-year
- Total energy: MMBTU/building-year; kBtu/ft^2-year[4]
- Energy cost: $/building-year; $/ft^2-year (based on local or standardized energy prices; nominal [not corrected for inflation] and inflation-corrected to a uniform year's currency)
- Percent energy use savings (total and by fuel)
- Percent total energy cost savings
- Persistence index: Post-commissioning energy use in a given year/pre-commissioning energy use (unitless ratio)

Commissioning cost
- $/building; $/ft^2 (based on nominal costs or, preferably, inflation-corrected to a uniform year's currency levels. Can be gross value or net, adjusting for the quantified value of non-energy impacts)
- Commissioning cost ratio, for new construction (commissioning cost / total building or renovation construction cost, %).[5]
- Costs are tabulated separately for the commissioning agent and other parties
- Allocation of costs by source of funds (building owner, utility, research grant, other)
- Total building construction cost (denominator for commissioning cost ratio)

Cost effectiveness
- Undiscounted payback time (commissioning cost/annualized energy bill savings). This indicator is preferably normalized to standard energy prices; costs and benefits are inflation corrected to a uniform year's currency levels

Deficiencies and measures
- Deficiencies/building; Deficiencies/100kft^2
- Measures/building; Measures/100kft^2
- Unique codes to identify combinations of deficiencies and measures (described in more depth below) [see Measures Matrix]

Commissioning scope
- Presence of pre-defined "steps" (yes/no), with different criteria for existing buildings and new construction

Non-energy impacts
- Type
- Quantified (when possible), $/building-year; $/ft^2-year [can be positive or negative] – one-time or recurring
- Yes/No (when not quantified)

[3] In some cases, multiple buildings will be aggregated, in which case data must be analyzed at the "project" level.
[4] Throughout this report, electricity is counted in "site" energy units, excluding losses in generation, transmission, and distribution, i.e., 3412 BTU/kWh.
[5] Commissioning cost as a percentage of total electrical or mechanical costs is often used as well.

Table 1:

Rules for inclusion of costs in scope of commissioning.

Cost Factor	Include Cost?	Relevance (**N**ew Construction, **E**xisting buildings)	Examples
Cx provider's fixed costs	Yes	N; E	Costs of developing commissioning spec, reviewing design documents, conducting inspections, construction observation
Other contractors' costs			
Contract compliance	No	N; E	Construct building; install systems
Testing and balancing (TAB)	No	N; E	Preceeds commissioning; separate service with separate fees
Coordination with commissioning provider	Yes	N; E	Assist in performing functional tests
Correcting design flaws	No	N	Included in design contract and warranty
Improving design or operations	Yes	N	Recommendations to reduce pressure-drop, improved control sequences (some opt to allocate this to "project" costs but not commissioning costs)
"Non-billable" in-house operations staff fixed costs	As desired by owner	N; E	Staff time to work with commissioning provider
Functional tests	Yes	N; E	Validating intended damper positions or variable-speed drive operating cycle
Resolution costs related to optimizing systems	Yes (existing), No (new)	N; E	Corrections during start-up; tune-up
Costs related to ensuring other trades' adherence to contract documents	Yes	N; E	Verifying as-built condition meets design intent
Resolution costs related to installing a system beyond project scope	No	N	Installing energy management and control systems; major capital retrofits
Resolution costs related to operations and maintenance	Yes	E	Cleaning fouled filters
Minor capital improvements to resolve deficiencies	Yes (existing), No (new)	N; E	Operations and maintenance
Major capital improvements to resolve deficiencies: new construction	No	N	Replacing incorrectly sized chiller. Capital improvements generally capped at those regarded as implementable within operating budgets (as opposed to capital budgets)
Major capital improvements to resolve deficiencies: existing buildings	Yes	E	Replacing faulty control system elements
Training or on-site staff	Yes, if in scope	N; E	
Utility rebates, grants, or other external financial assistance	Yes	N; E	Represents part of true project cost and should thus be included (although owner's may opt to exclude for the purposes of their own internal cost-benefit analysis)
Research-related costs	No	N; E	Development of research reports; not essential to efficacy of commissioning project
Travel	Yes	N; E	To and from project site
Non-energy impacts	Yes	N; E	Subtract from total cost if benefit; add to total cost if non-energy factor imposes an incrementaql cost

Table 2: **Example of Measures Matrix used to characterize commissioning projects.**

Project A. Hospital Facility

	Components (locus of fault)										Measures																		Measure Code	Implemented [Y;N;?]	Detail problems and remediation measures
											Design, Installation, Retrofit, Replacement				Operations & Control									Maintenance							
	HVAC (combined heating and cooling)	Cooling plant	Heating plant	Air handling & distribution	Terminal units	Lighting	Envelope	Plug loads	Facility-wide (e.g. EMCS or utility related)	Other	Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other			
	V	C	H	A	T	L	E	P	F	O	D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4	M5			
			x																					x					H-M1	Y	Setpoint controller on boiler 1 was out of calibration by 20F
				x																x									A-OC6	Y	Night low limit should only control perimeter boxes with reheat, not core boxe
						x											x												L-OC3	Y	All exterior lighting ON all night per programming. Changed outside lighting 2:45 am.
				x											x														A-OC1	Y	Discharge air temperature reset schedule was not programmed. Added rese
				x														x											A-OC4	Y	Cooling-only VAV box min setting supposed to be 0, but set at 56%. Simulta heating and cooling with an adjacent zone.
				x														x											A-OC4	Y	Differential omitted from night high limit sequence and night low limit sequen cycling of AHU.
				x																x									A-OC6	Y	Outside air dampers don't close during optimal start and night low limit
	x																											x	V-M5	Y	Poor system documentation. Unclear and incomplete control sequences. Di flow rates for control valves or location of duct smoke detectors and backflov Improved documentation for O&M manuals
			x															x											H-OC4	Y	Firing rate controller setting on both boilers were wrong. High limit supposec 20F>low limit. It was reversed.
				x																x									A-OC6	Y	Confusion as to what the BAS will control and what the Trane RTU will contr straight and programmed.
									x														x						F-OC9	Y	Current trending capability is limited to 1 parameter per trend and can only b one parameter at a time. Inconvenient for troubleshooting and fine tuning.G interface with full graphing capabilities.
			x									x																	H-D2	Y	Isolation valves to boilers missing. HW supply temp cannot be controlled or by mixing valve when only 1 boiler is on. Valves and controls added.
					x																			x					T-M1	Y	Nine out of the nine thermostats were out of calibration. JCI didn't use a cali thermometer and used +/- 2F as acceptable. JCI sensors used are rated to specs call for +/- 0.5F calibration.
			x																				x						H-OC9	Y	Alarms on boilers had been disabled. Enabled alarms.
				x								x																	A-D2	Y	ASU-1 & 2 didn't have duct static pressure sensors hooked up.
	x																							x					V-M1	Y	OAT sensor calibration 2.5 degrees off. Recalibrated.
	x											x																	V-D2	Y	Installation problems: : ductwork high SP loss fittings, duct sealing, sheetroc coils, exhaust fan not wired, valve not hooked up, timeswitch doesn't start fa won't start by adjusting thermostat, TU zero calibration not enabled, exhaust connected, disconnects on boilers missing
									x											x									F-OC6	Y	Power outage sequences: not programmed correctly
					x							x																	T-D2	Y	Duct crushed 12" from TU inlet to make room for sprinkler pipe. Erratic TU f Sensor relocated.
Other:																														Y	93 Other findings not tabulated
Rejected																															
Count or total:	3	0	4	7	2	1	0	0	2	0	0	4	0	0	1	0	1	3	0	4	0	0	2	3	0	0	0	1			
Grand Totals:	19										19																				

Note: "Measure Code" is a unique code assigned based on each measure's corresponding deficiency and type. The full Measures Matrix also contains fields for persistence, savings measurement method, and energy impacts.

Table 3:

Energy and non-energy impacts (positive or negative) of commissioning.

	Cost	Benefit	Comment
Direct			
Cost of (retro)commissioning service	x	x	Cost can be partially or completely offset by the indirect effects listed below
Energy consumption	x	x	In rare circumstances, energy use can increase if equipment is found in "off" or under-utilized state
Indirect			
Accelerated repair of a problem (assuming it would have been identified and corrected, eventually, without commissioning)		x	
Avoided premature equipment failure		x	
Changes in ioperations and maintenance costs	x	x	
Changes in project schedule	x	x	Can shorten or lengthen schedule
Clarified delineation of responsibilities among team members		x	
Contractor call-backs		x	
Occupant comfort/productivity		x	
Equipment right-sizing	x	x	
Impacts on indoor environment		x	
Documentation	x	x	
In-house staff knowledge	x	x	
Disruption to occupancy and operations	x	x	Early detection of problems
More vigilant contractor behavior (knowing that Cx will follow their work)		x	
Operational efficacy		x	
Potential for reduced liability/litigation		x	
Change orders	x	x	Timely introduction of commissioning (early in process); otherwise potential for increase
Disagreement among contractors		x	
Testing and balancing (TAB) costs		x	Can be reduced by solving problems that the TAB contractor would otherwise have encountered
Safety impacts		x	
Warranty claims		x	
Water utilization		x	
Worker productivity		x	

Table 4:

Commissioning providers, by floor area.

	Existing Buildings (square feet)	%	New Construction (square feet)	%
Affiliated Engineers, Inc. (Walnut Creek, CA)	-	-	774,000	9.5%
CH2M Hill (Portland OR)	-	-	340,000	4.2%
Environmental and Engineering Services, Inc.	-	-	160,000	2.0%
Facility Dynamics (Baltimore, MD)	1,014,133	4.6%	-	-
Facility Improvement Corporation (Great Falls, MT)	64,000	0.3%	-	-
Farnsworth Group	-		1,083,758	13.3%
HEC (ESCO)	376,500	1.7%	165,000	2.0%
Herzog/Wheeler	44,000	0.2%	-	-
Keithly/Welsch Associates Inc (Burien WA)	65,000	0.3%	144,000	1.8%
Nexant (San Francisco, CA)	210,406	0.9%	-	0.0%
Northwest Engineering Service, Inc.	213,000	1.0%	-	0.0%
PECI (Portland, OR)_	4,345,810	19.5%	371,000	4.5%
Quantum Energy Services and Technologies, Inc. - QuEST (Oakland, CA)	2,132,411	9.6%	-	-
Sieben Energy	623,000	2.8%	-	-
Systems West Engineers (Eugene, OR)	172,400	0.8%	-	-
TAMU/ESL College Station TX)	9,439,042	42.5%	-	-
Test Comm LLC (Spokanne, WA)	-	-	60,000	0.7%
Western Montana Engineering	-	-	23,300	0.3%
Other	3,531,592	15.9%	5,046,400	61.8%
Total	**22,231,294**	**100%**	**8,167,457**	**100%**

Table 5:

Summary of results.

	All		Existing Buildings			New Construction		
	Total	sample size (Number of	Total	Median per project	Study sample size	Total	Median per project	Study sample size
Number of projects	175	175	106		106	69		69
Number of buildings [1]	224	175	150	**1.4**	106	74	**1.1**	69
Number of states	21	175	15		106	15		69
Total project floor area (million ft^2)	30.4	175	22.2	**0.151**	106	8.2	**0.07**	69
Building age				**1978**	78		**1996**	59
Total new building construction costs ($million) [2]						1,514	**10.2**	58
Number of deficiencies identified	6,805	120	3,500	**11**	85	3,305	**26**	35
Commissioning cost as a fraction of total building construction cost (excluding non-energy benefits) [%]							**0.6%**	65
Total commissioning costs ($2003), excluding non-energy impacts [3]								
$1,000	16,984	171	5,223	**34**	102	11,760	**74**	69
$/ft2				**0.27**	102		**1.00**	69
Total Savings ($2003) [3]								
$1000/year[4]	8,840	133	8,022	**45**	100	818	**3**	33
$/ft2-year [4]				**0.27**	100		**0.05**	33
Whole-building energy cost savings (%) [5]				**15%**	74			
Simple payback time, local energy prices [years]				**1.0**	99		**5.6**	38
Simple payback time: standardized US energy prices, including some cases with non-energy impacts [years] [6]				**0.7**	59		**4.8**	35

[1] Actual values likely higher. For the many data sources that did not specify number of buildings, we stipulated one.
[2] All costs in this table are in inflation-corrected 2003 dollars.
[3] Payback time should not be inferred from these two rows, as sample sizes are different.
[4] Total based on inflation-corrected local energy prices; median based on inflation-corrected standardized energy prices ($2003).
[5] Percentage savings are generally not available for new construction, as there is no opportunity to measure energy use in the hypothetical (un-built) un-commissioned building.
[6] A number of cases show commissioning costs partly or fully offset by resultant first-cost savings.

Table 6:

Results from Measures Matrices: Existing buildings (69 projects) [yellow highlights indicate most common measures, deficiencies, and combinations].

		Design, Installation, Retrofit, Replacement				Operations & Control									Maintenance						
N (paired) = 702		Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other	Deficiency unmatched to specific measure	Total
Deficiencies		**D1**	**D2**	**D3**	**D4**	**OC1**	**OC2**	**OC3**	**OC4**	**OC5**	**OC6**	**OC7**	**OC8**	**OC9**	**M1**	**M2**	**M3**	**M4**	**M5**		
HVAC (combined heating and cooling)	**V**	0	2	8	1	1	1	5	3	1	5	0	0	2	5	7	1	5	2	12	61
Cooling plant	**C**	4	11	19	0	26	5	4	10	4	27	3	12	2	4	10	1	0	0	13	155
Heating plant	**H**	4	0	5	0	15	7	1	4	0	7	1	5	1	4	7	1	0	0	18	80
Air handling & distribution	**A**	15	9	19	3	80	9	21	25	4	24	12	14	6	40	27	3	4	2	40	357
Terminal units	**T**	1	3	2	1	4	0	3	14	0	4	1	2	1	7	10	0	0	0	8	61
Lighting	**L**	3	1	17	1	1	2	4	0	0	0	0	5	0	2	1	0	0	0	1	38
Envelope	**E**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plug loads	**P**	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Facility-wide (e.g. EMCS or utility related)	**F**	2	3	2	0	1	0	7	0	0	1	1	7	2	2	2	1	0	0	3	34
Other	**O**	0	0	2	0	0	0	0	2	0	1	0	1	0	0	3	0	0	1	12	22
Deficiency unmatched to specific measure		10	9	7	0	2	2	1	29	2	7	2	4	1	12	10	0	0	0		**809**
Total		39	38	81	6	130	26	46	87	11	76	20	51	15	76	77	7	9	5	**800**	

Table 7:

Results from Measures Matrices: New construction (20 projects) [yellow highlights indicate most common measures, deficiencies, and combinations]

		Measures																			
		Design, Installation, Retrofit, Replacement				Operations & Control									Maintenance						
N (paired) = 157		Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other	Deficiency unmatched to specific measure	Total
Deficiencies		**D1**	**D2**	**D3**	**D4**	**OC1**	**OC2**	**OC3**	**OC4**	**OC5**	**OC6**	**OC7**	**OC8**	**OC9**	**M1**	**M2**	**M3**	**M4**	**M5**		
HVAC (combined heating and cooling)	**V**	0	8	0	0	2	0	0	3	1	0	1	0	3	6	9	1	2	2	108	146
Cooling plant	**C**	0	3	0	0	0	1	0	1	0	1	1	0	1	1	2	0	0	0	84	95
Heating plant	**H**	1	1	0	0	0	0	0	1	1	1	1	0	1	2	0	0	0	0	49	58
Air handling & distribution	**A**	0	7	2	0	1	0	0	3	0	7	2	0	4	2	14	1	0	3	222	268
Terminal units	**T**	1	5	0	0	0	0	2	5	0	2	1	0	0	3	1	0	1	0	98	119
Lighting	**L**	0	0	0	0	0	0	1	0	0	0	0	0	0	8	1	0	0	0	161	171
Envelope	**E**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plug loads	**P**	0	1	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	81	85
Facility-wide (e.g. EMCS or utility related)	**F**	0	1	0	0	0	0	0	0	1	2	0	0	8	0	3	0	0	0	69	84
Other	**O**	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	108	111
Deficiency unmatched to specific measure		12	82	4	22	0	0	0	90	37	52	133	0	14	78	140	14	3	263		**1137**
Total		14	108	6	22	3	1	3	103	41	66	139	0	31	103	171	16	6	268	**1101**	

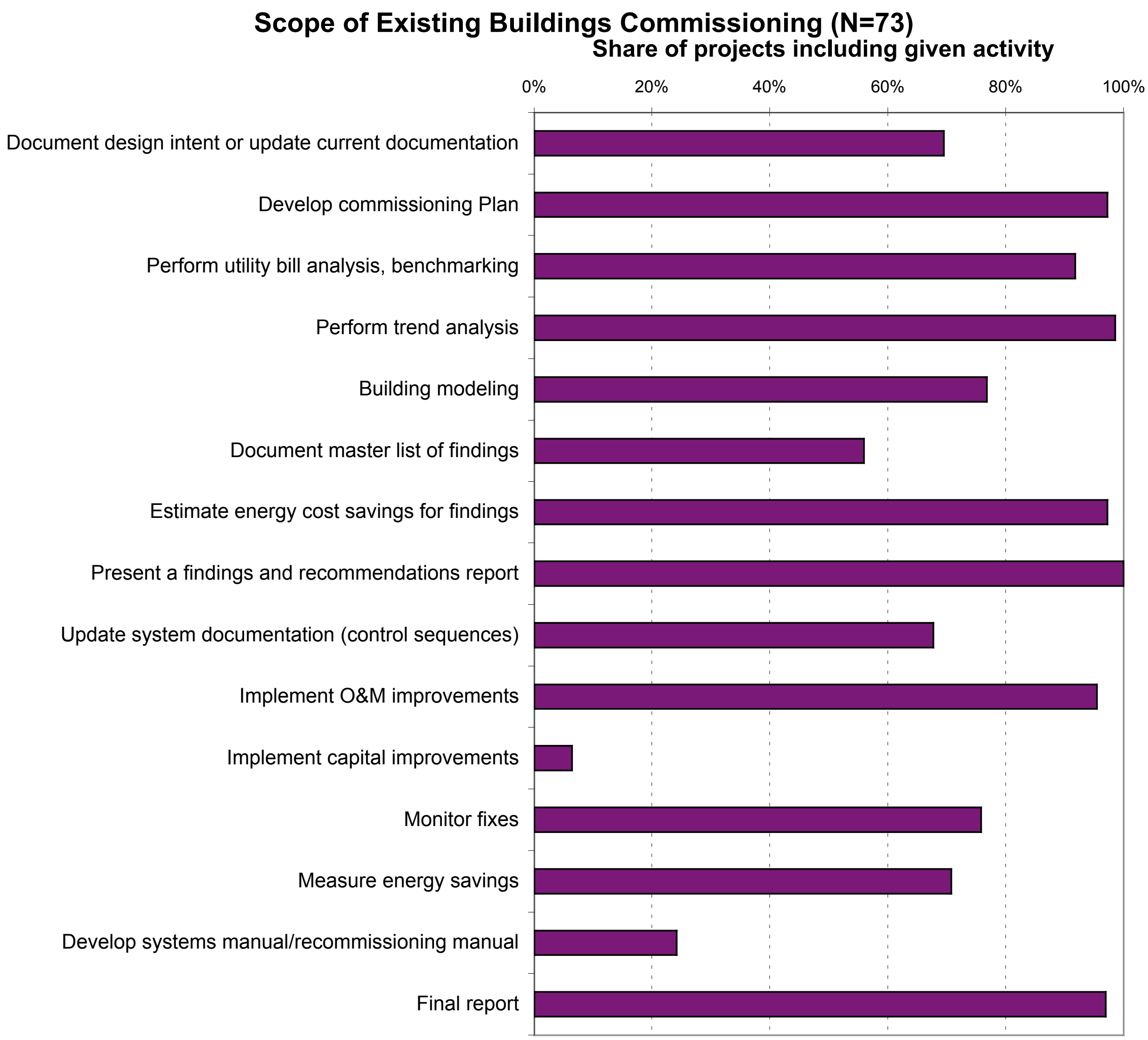

Scope of Existing Buildings Commissioning (N=73)
Share of projects including given activity
0%
20%
40%
60%
80%
100%
Document design intent or update current documentation
Develop commissioning Plan
Perform utility bill analysis, benchmarking
Perform trend analysis
Building modeling
Document master list of findings
Estimate energy cost savings for findings
Present a findings and recommendations report
Update system documentation (control sequences)
Implement O&M improvements
Implement capital improvements
Monitor fixes
Measure energy savings
Develop systems manual/recommissioning manual
Final report

Figure 1:

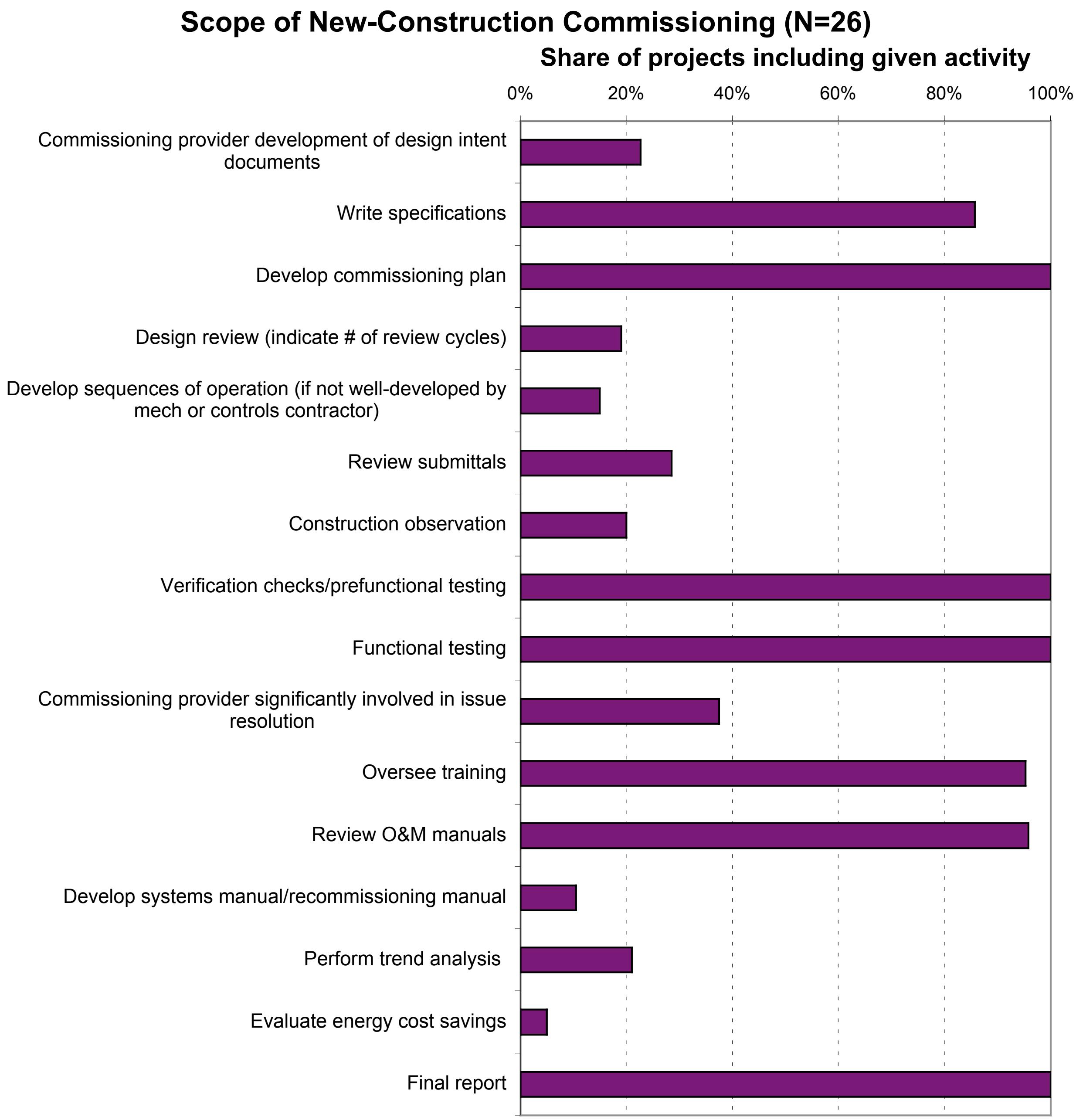
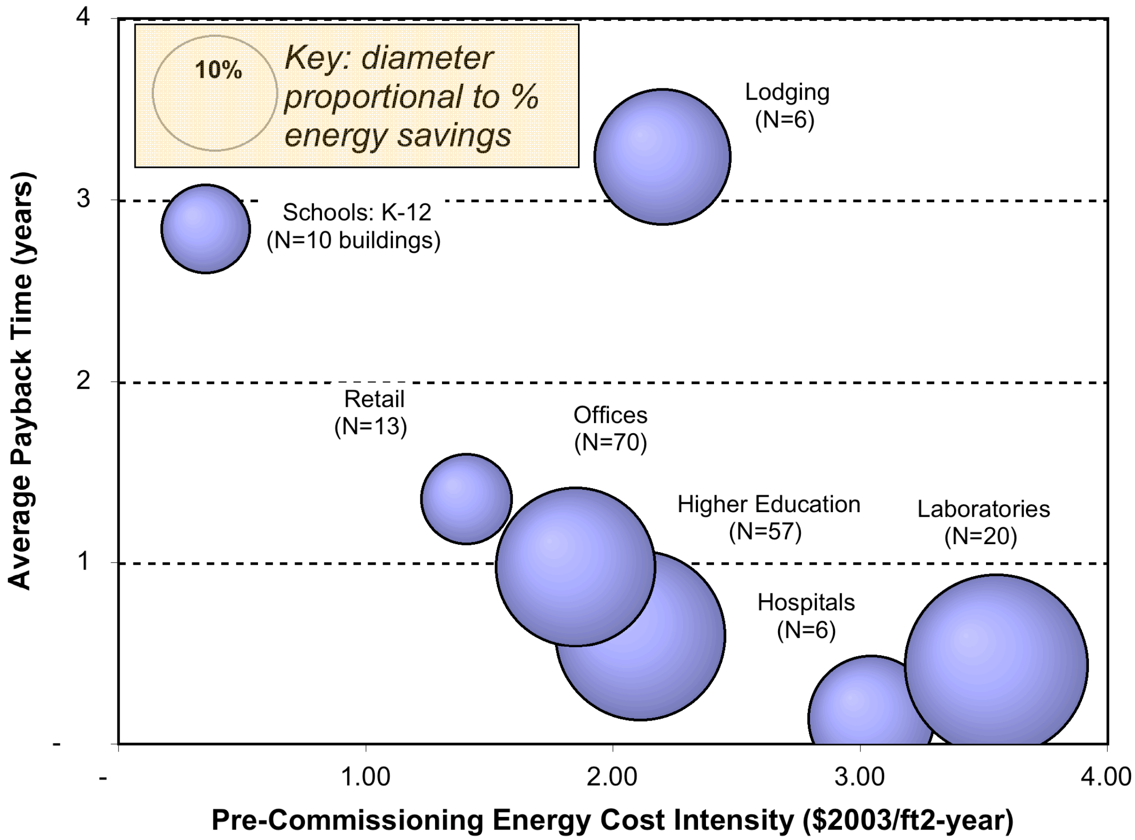
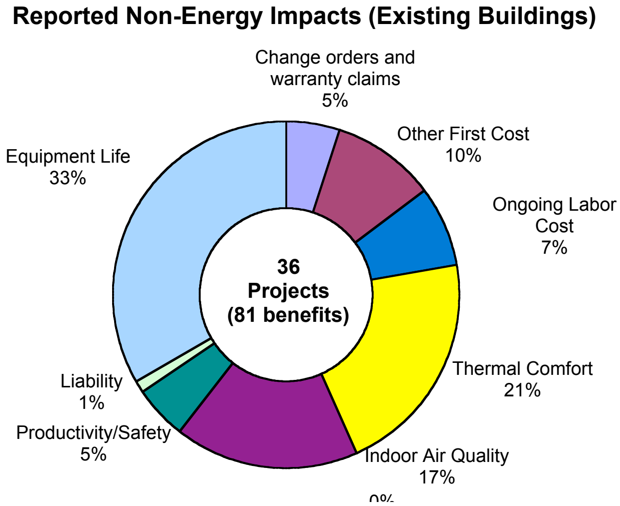

Scope of New-Construction Commissioning (N=26)
Share of projects including given activity
0%
20%
40%
60%
80%
100%
Commissioning provider development of design intent documents
Write specifications
Develop commissioning plan
Design review (indicate # of review cycles)
Develop sequences of operation (if not well-developed by mech or controls contractor)
Review submittals
Construction observation
Verification checks/prefunctional testing
Functional testing
Commissioning provider significantly involved in issue resolution
Oversee training
Review O&M manuals
Develop systems manual/recommissioning manual
Perform trend analysis
Evaluate energy cost savings
Final report

Figure 2:



Existing buildings. (Excluding non-energy impacts).

Figure 3:



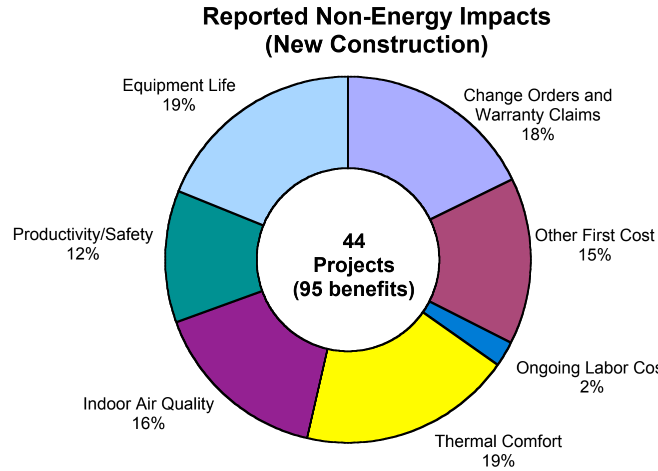
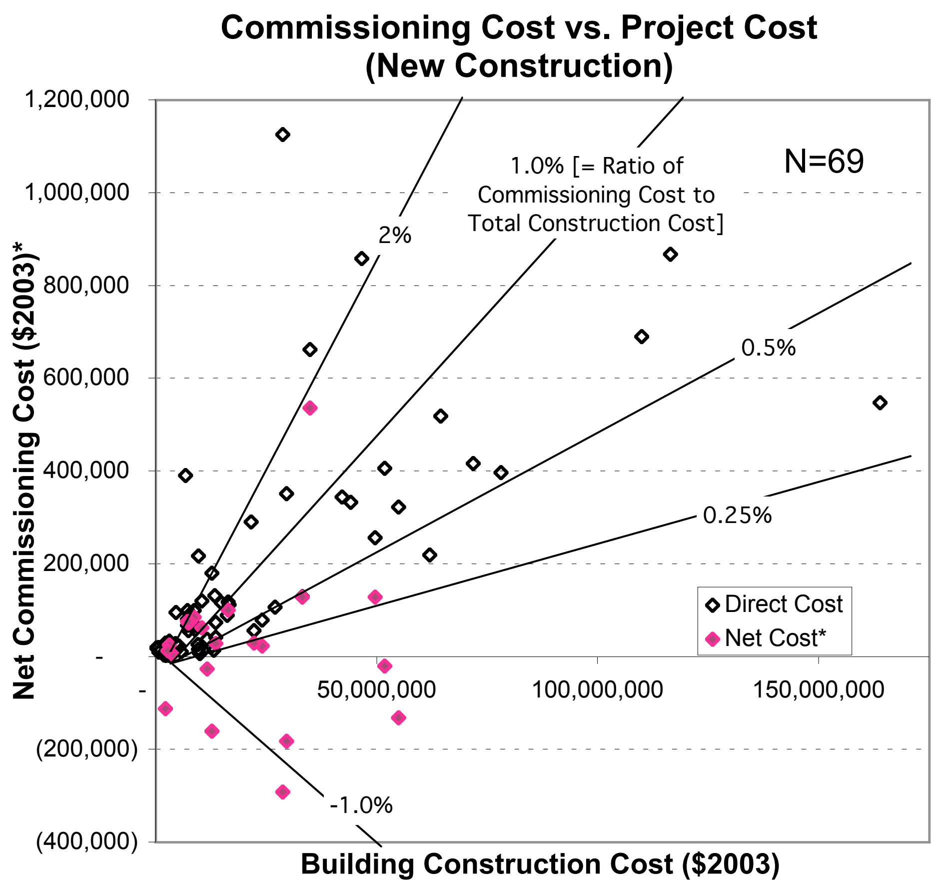


Figure 4:



* including non-energy impacts

Figure 5:

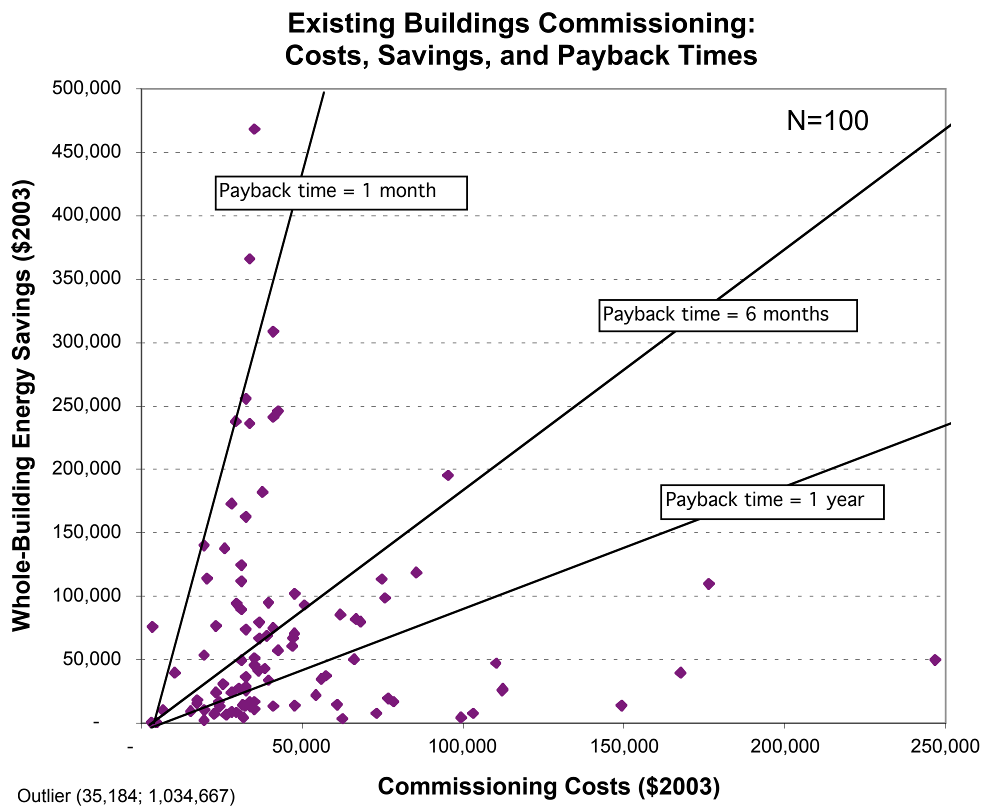


Figure 6:

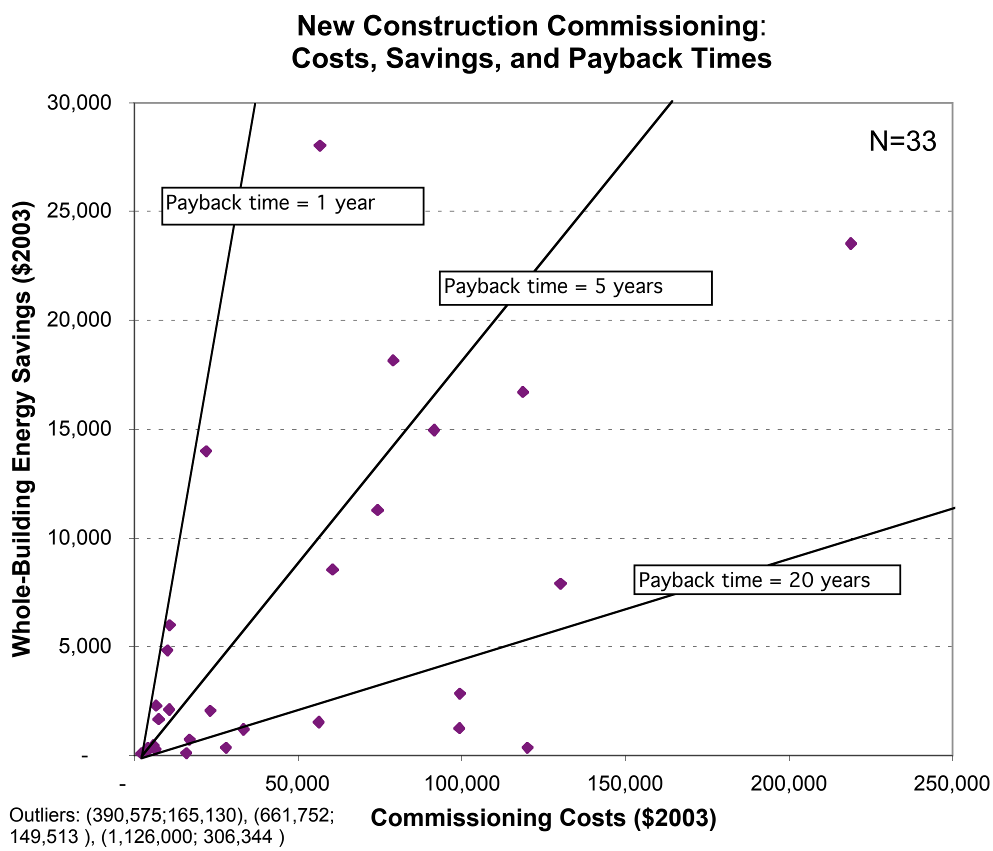


Figure 7:

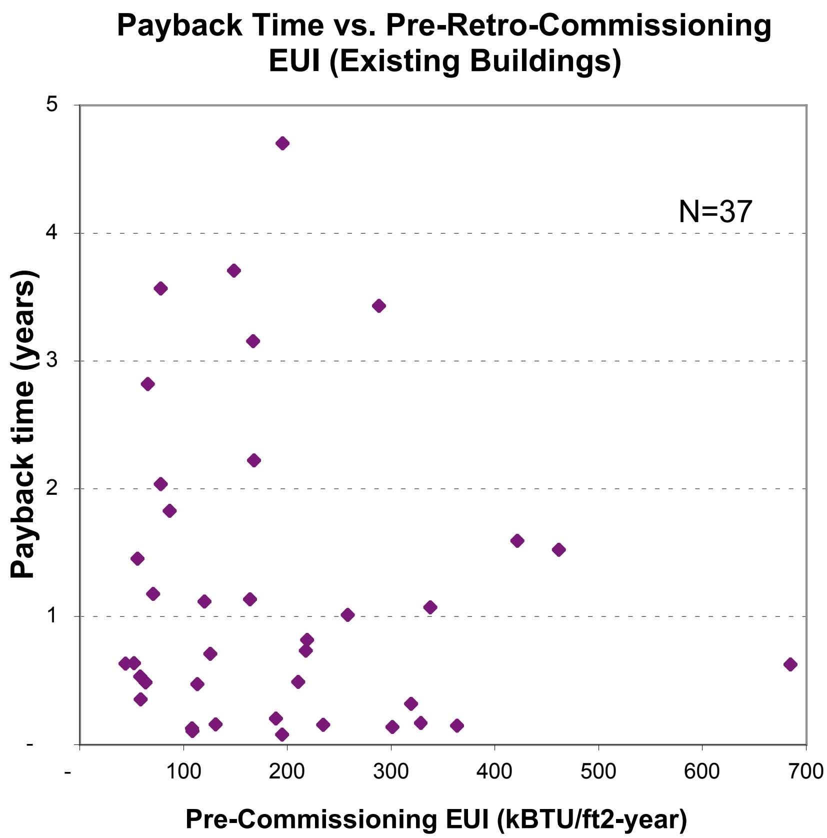


Figure 8:

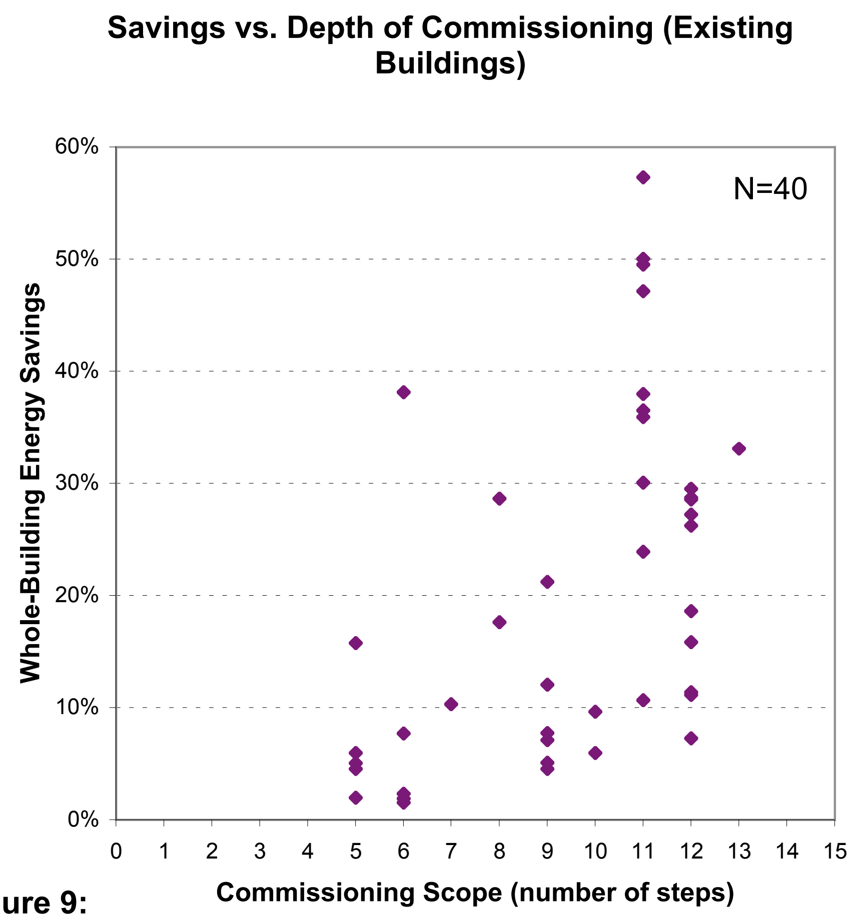


Figure 9:

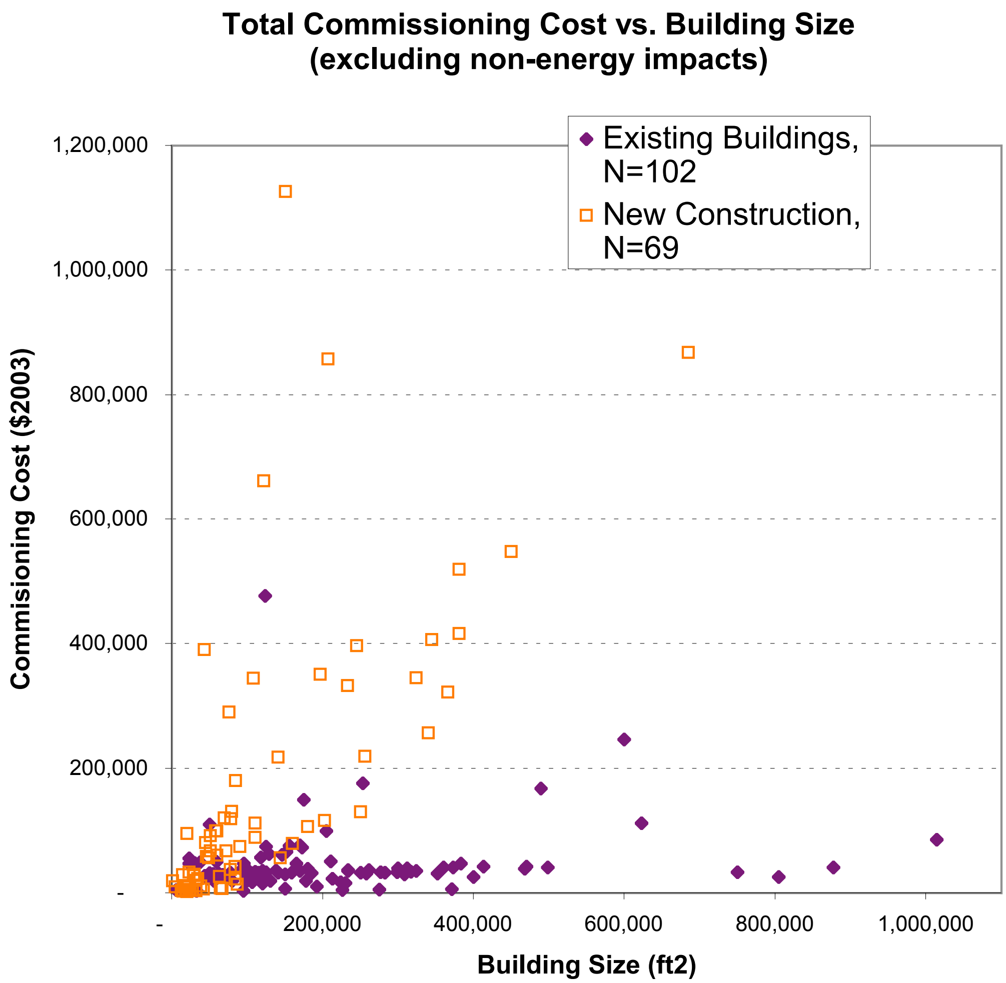

Total Commissioning Cost vs. Building Size
(excluding non-energy impacts)
Existing Buildings, N=102
New Construction, N=69
1,200,000
1,000,000
800,000
600,000
400,000
200,000
-
Commisioning Cost ($2003)
-
200,000
400,000
600,000
800,000
1,000,000
Building Size (ft2)

Figure 10: